ETCHING APPARATUS AND ETCHING METHOD

BACKGROUND OF THE INVENTION

The present invention relates to etching apparatus and etching methods.

FIG. **12** schematically shows a conventional dry etching apparatus for use in etching of an oxide film or other films.

As shown in FIG. **12**, a substrate **20** to be processed is mounted on a lower electrode **12** provided on the bottom of a reaction chamber **11**. An upper electrode **13** is provided at the ceiling of the reaction chamber **11** to face the lower electrode **12** with a space in which plasma is to be generated interposed there between. An RF power supply **14** for applying power at 13.56 MHz to the lower electrode **12** is provided in the outside of the reaction chamber **11**. A gas inlet **15** for introducing a process gas into the reaction chamber **11** and a gas outlet **16** for letting out the process gas from the reaction chamber **11** is each provided through the side wall of the reaction chamber **11**. A focus ring mainly composed of silicon (Si focus ring) **17** is provided on the lower electrode **12** and surrounds the substrate **20**.

Although not shown, a silicon oxide film as an object to be etched (hereinafter, referred to as an etching object) is formed over the substrate **20** with a silicon nitride film, for example, interposed there between.

FIG. **13** is a plan view showing a structure of the Si focus ring **17** shown in FIG. **12**, i.e., a conventional focus ring. As shown in FIG. **13**, the Si focus ring **17** is a single ring having, at its center, an opening whose diameter corresponds to the diameter of the substrate **20**, i.e., wafer.

In the dry etching apparatus shown in FIG. **12**, a member made of silicon is placed

inside the reaction chamber **11**, more specifically, the Si focus ring **17** is placed on the periphery of the lower electrode **12**, so that the SiO_2/Si selectivity is enhanced. This is because of the following reasons. That is, in the reaction chamber **11**, silicon constituting the Si focus ring **17** reacts with etching gas radicals, so that the etching gas radicals are scavenged and the density of the etching gas radicals decreases. Accordingly, the etching gas / the etchant ratio increases and thereby the etching rate of silicon decreases, thereby enhancing the SiO_2/Si selectivity. That is, the focus ring has a function of controlling the density of radicals or ions by reacting with the radicals or ions in the plasma (see, for example, Japanese Patent No. 3333177 (pp 11 to 12), Japanese Patent Laid-Open Publication No. 7-245292 (p2), Japanese Patent Laid-Open Publication No. 8-186096 (p2), Japanese Patent Laid-Open Publication No. 2002-9048 (FIG. 4), Japanese Patent Laid-Open Publication No. 2002-164323 (p3) and Japanese Patent Laid-Open Publication No. 2002-190466 (p2)).

In the past, oxide-film etching was mainly used for forming, for example, a contact hole in an oxide film. However, with recent progress of miniaturization found in ITRS (International Technology Roadmap for Semiconductor), the thickness of resists has been reduced, resulting in that hard masks made of oxide films or other materials have come to be adopted in conventional etching processes in which resist patterns are used as masks. As a typical example, a hard mask of an oxide film is used in an etching process for forming a gate electrode of polycrystalline silicon.

However, if the conventional dry etching apparatus shown in FIG. **12** is used in patterning the above-mentioned hard mask of the oxide film, the following problems arise.

FIGS. **14A** and **14B** are views for explaining problems in oxide-film etching using the conventional dry etching apparatus.

As shown in FIG. **14A,** a resist pattern **22** having, for example, a gate electrode

pattern is formed on an oxide film **21** as an etching object. This resist pattern **22** has a width L_0 (critical dimension after lithography). Thereafter, as shown in FIG. **14B**, the oxide film **21** is etched using the resist pattern **22** as a mask, thereby patterning the oxide film **21**. The patterned oxide film **21A** has a width L_1 (critical dimension after dry etching).

However, in the case of using the conventional dry etching apparatus, there arise a problem in which the oxide film **21** after etching (i.e., the patterned oxide film **21A** in cross section) does not have a desired vertical shape but a tapered shape, as shown in FIG. **14B**. There also arises another problem of an increased amount of a critical dimensional shift (critical dimension L_1 after dry etching – critical dimension L_0 after lithography).

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to allow an etching to be performed with the amount of the critical dimensional shift suppressed and a desired etched shape obtained, irrespective of a pattern to be formed. More specifically, an object of the present invention is to obtain a desired etched shape while suppressing the amount of the critical dimensional shift, irrespective of a pattern to be formed.

In order to achieve this object, the present inventor studied to find causes of increase in the amount of a critical dimensional shift and deterioration of controllability of an etched shape under following one of considerations.

Hereinafter, a method for performing etching on an oxide film using the conventional etching apparatus shown in FIG. **12** will be described specifically.

First, a fluorocarbon gas such as a C_4F_8, C_5F_8 or CF_4 gas as a reactive gas is supplied to the reaction chamber **11** through the gas inlet **15**, thereby generating plasma made of the gas. In this plasma, the following dissociation occurs:

$C_4F_8 \rightarrow C_4F_7 + F$ or

$C_xF_{y+1} \rightarrow C_xF_y + F$

As a result, radicals (activated species) or ions of C_xF_y (where x and y are natural numbers) or F (fluorine) are supplied onto the substrate **20**.

At this time, a reaction expressed by

$$SiO_2 + F \rightarrow SiF_x + O^* \qquad \text{(Equation 1)}$$

occurs between the oxide film (SiO_2 film) over the substrate **20** and, for example, fluorine radicals, so that etching of the oxide film (hereinafter, referred to as oxide-film etching) proceeds. In this manner, the oxide film is processed.

The fluorocarbon (C_xF_y) radicals generated from the plasma produces a polymer (fluorocarbon polymer) of carbon and fluorine over the oxide film as the object to be etched. However, a reaction expressed by

$$C_xF_y + O^* \rightarrow CO_x + F \qquad \text{(Equation 2)}$$

occurs between O* (oxygen radical) generated through the reaction expressed by Equation 1 and the fluorocarbon polymer, so that the fluorocarbon polymer on the oxide film is removed.

On the other hand, when the oxide-film etching is produced and the silicon substrate or the silicon nitride film under the oxide film are exposed, the generation of O* as shown in Equation 1 does not occur. Accordingly, the removal of the fluorocarbon polymer caused by the oxygen radicals as expressed by Equation 2 does not occur. That is, the fluorocarbon radicals cause the fluorocarbon polymer to be deposited on the silicon substrate or the silicon nitride film. As a result, the etching rate of silicon or the silicon nitride film decreases, thus securing the selectivity between the oxide film and its underlying silicon or silicon nitride film. The SiO_2/Si selectivity (or SiO_2/SiN selectivity) generally depends on the ratio of fluorocarbon radicals to fluorine radicals (hereinafter,

referred to as a C_xF_y/F ratio) in the plasma in general. Specifically, as the_C_xF_y/F ratio increases, the etching rate of silicon decreases, so that the SiO_2/Si selectivity increases. In contrast, as the C_xF_y/F ratio decreases, the etching rate of silicon increases, so that the SiO_2/Si selectivity decreases. In this way, the control of the C_xF_y/F ratio is very important in oxide-film etching.

That is, in oxide-film etching for, for example, forming a contact hole for which the conventional etching apparatus has been used without problems, the opening area ratio of the oxide film as an object to be etched is about several percent at most. The opening area ratio is herein the ratio of the area of the oxide film to be removed by etching with respect to the entire area of the oxide film before etching. In other words, the opening area ratio is the ratio of the area of apertures in the oxide film per one chip with respect to the area of the chip.

On the other hand, in oxide-film etching for forming, for example, an oxide-film hard mask having a gate electrode pattern, which involves a problem if the conventional etching apparatus is used, the opening area ratio of the oxide film is as high as about 20 to 80 %, which is much higher than the opening area ratio in conventional contact-hole formation.

The present inventor found out that the above problems occur when oxide-film etching with a high opening area ratio is performed using the conventional etching apparatus in which the C_xF_y/F ratio in the reaction chamber is enhanced by the shield comprised a Si focus ring for forming, for example, a contact hole. Specifically, in this case, the amount of fluorine radicals, i.e., an etchant (etching species), is insufficient for the area of the oxide film to be etched, whereas fluorocarbon radicals to be a cause of polymer deposition, i.e., deposition species, is in excess. As a result, an appropriate C_xF_y/F ratio is not obtained in the reaction camber, so that the amount of a critical dimensional

shift increases and the controllability of the etched shape (hereinafter, referred to as shape controllability) deteriorates.

In addition, based on the foregoing findings, the present inventor came up with the idea of solving the above-described problems by adjusting the surface area of the shield of the etching apparatus in accordance with the opening area ratio of the object to be etched. Specifically, in the case of oxide-film etching, if the surface area of the shield composed of Si for scavenging fluorine radicals in a plasma is changed in accordance with the opening area ratio of an oxide film, the C_xF_y/F ratio over the oxide film is optimized, thus preventing increase in the amount of a critical dimensional shift and deterioration of the shape controllability.

Further, the present inventor also came up with the idea of forming a shield using Si that reacts with fluorine radicals in the plasma and also using a material (e.g., SiC, SiO_2, Al_2O_3 or Y_2O_3) having low reactivity with the fluorine radicals to control the amount of scavenged fluorine radicals at points on the shield and thereby improve the uniformity of the C_xF_y/F ratio in the wafer surface.

The present invention has been made based on the foregoing findings. Specifically, a first etching apparatus according to the present invention is based on an etching apparatus including a shield provided on an electrode in a reaction chamber and surrounding an object to be etched. In this first etching apparatus, the shield has a surface area according to an opening area ratio of the object to be etched.

With the first etching apparatus, the shield has a surface area according to the opening area ratio of the object to be etched, so that the amount of scavenged etchant such a fluorine radical in plasma is controlled in accordance with the opening area ratio of the object to be etched. Specifically, a shield having a surface area which decreases as the opening area ratio of the object to be etched (i.e., the area to be etched) increases is used,

so that the amount of scavenged etchant such a fluorine radical is reduced. On the other hand, a shield having a surface area which increases as the opening area ratio of the object to be etched decreases is used, so that the amount of scavenged etchant such fluorine radical is increased. Accordingly, it is possible to perform the etching such that the amount of a critical dimensional shift is suppressed and a desired etched shape is obtained, irrespective of a pattern to be formed.

A second etching apparatus according to the present invention is based on an etching apparatus including a shield provided on an electrode in a reaction chamber and surrounding an object to be etched. In this second etching apparatus, the shield is constituted by one shield unit or a combination of two or more units selected from a plurality of units which have been prepared beforehand and have different radiuses such that the shield has a surface area according to an opening area ratio of the object to be etched.

With the second etching apparatus, the shield is constituted by one unit or a combination of two or more units selected from a plurality of units with different radiuses such that the unit has a surface area according to the opening area ratio of the object to be etched. That is, in the second etching apparatus, as in the first etching apparatus, the shield also has a surface area according to the opening area ratio of the object to be etched, so that the same effects as in the first etching apparatus are obtained. In addition, the surface area of the shield is adjusted easily.

The size of a shield herein is the length from the center to the outer periphery (outside shield) of the shied having a given width, except where specifically noted. The first and second etching apparatuses are based on the premise that the shield is provided on the electrode such that the inner side of the shield is in contact with the edge of the substrate (wafer) over which the object to be etched (e.g., an oxide film) is formed. In

other words, the shield according to the present invention has an opening corresponding to the diameter of the wafer at its center. Accordingly, the surface area of the shield is herein the area of a portion of the shield exposed to plasma in the reaction chamber, i.e., the total area of the upper and outside surfaces of the shield surrounding the object to be etched.

In the second etching apparatus, the plurality of shield units constituting the shield is fit together with no gaps there between. Specifically, shield units are combined such that the outer side of a shield unit with a smaller size is in contact with the inner side of a shield unit with a larger size.

In the second etching apparatus, each of the plurality of shield units preferably contains silicon as a main component.

Then, in the case of oxide-film etching (i.e., in a case where the object to be etched is an oxide film), the surface area of the shield containing silicon as a main component is adjusted in accordance with the opening area ratio of the oxide film as the object to be etched. This allows the control of the amount of scavenged etchant for the oxide film (e.g., fluorine radicals in the plasma), thus optimizing the amount ratio (e.g., C_xF_y/F ratio) between the deposition species (e.g., C_xF_y radicals in the plasma) and the etchant on the oxide film. As a result, it is possible to obtain a desired etched shape while suppressing the amount of a critical dimensional shift during oxide-film etching, irrespective of a pattern to be formed, as intended.

In the second etching apparatus, the plurality of shield units preferably include at least two shield units whose main components differ from each other.

Then, the shield is constituted by a shield unit (or a plurality of shield units) containing a material exhibiting a high etchant scavenging ability as a main component and another shield unit (or a plurality of shield units) containing a material exhibiting a low etchant scavenging ability as a main component. With this structure, a sharp change in the

amount of the etchant on the shield unit (i.e., on the periphery of the wafer) is suppressed, so that the uniformity in the wafer surface regarding, for example, the etching ratio of the object to be etched, the selectivity between the object to be etched and its underlying material or the etched shape is improved.

The phrase of "containing a material as a main component" herein includes "made of only one material".

In the second etching apparatus, the plurality of shield units preferably includes a first shield unit containing silicon as a main component and a second shield unit containing a material other than silicon as a main component.

Then, in the case of oxide-film etching (i.e., in a case where the object to be etched is an oxide film), the shield is constituted by a first shield unit (or a plurality of shield units) containing a material exhibiting a high etchant (e.g., fluorine radicals) scavenging ability as a main component and a second shield unit (or a plurality of shield units) containing a material exhibiting a low etchant scavenging ability as a main component. With this structure, a sharp change in the amount of the etchant on the shield (i.e., on the periphery of the wafer) is suppressed and thus the amount ratio (e.g., C_xF_y/F ratio) between the deposition species (e.g., C_xF_y radicals) and the etchant is also suppressed. Accordingly, the uniformity in the wafer surface regarding, for example, the etching ratio of the oxide film, the selectivity between the oxide film and its underlying material or the etched shape is improved. If said material other than silicon contains at least one material selected from the group consisting of quartz (SiO_2), silicon carbide (SiC), aluminum oxide (Al_2O_3) and yttrium oxide (Y_2O_3), the improvement of the uniformity in the wafer surface regarding, for example, the etching ratio is ensured.

In the second etching apparatus, the plurality of shield units preferably includes at least a shield unit containing, as a main component, the same material as the object to be

etched.

Then, in the case of etching of, for example, an oxide film (a SiO_2 film), if a shield including a shield of SiO_2 is used, the area to be etched (SiO_2 area), i.e., the opening area ratio, is increased in effect. In other words, if a shield is formed using a ring containing the same material as the object to be etched as a main component, the area to be etched is substantially increased. In this manner, the amount of an etchant supplied onto a portion to be etched (under an opening of a resist mask) on an object to be etched having an opening area ratio of, for example, about several percent is adjusted to substantially the same amount as an etchant supplied to a portion to be etched on an object to be etched having an opening area ratio of, for example, about several tens percent. That is, only by adjusting the structure of the shield, etching can be performed with high accuracy on etching objects having various opening area ratios using the same etching apparatus.

An etching method according to the present invention is based on an etching method using an etching apparatus including a shield which is provided on an electrode in a reaction chamber and surrounds an object to be etched. The method includes the steps of: mounting the object to be etched on the electrode; introducing a gas into the reaction chamber to generate a plasma of the gas and performing etching on the object to be etched by using the plasma; and adjusting the surface area of the shied in accordance with an opening area ratio of the object to be etched, before the step of performing etching.

With the inventive etching method, in performing etching, the surface area of the shield is adjusted in accordance with the opening area ratio of the object to be etched, so that the amount of scavenged etchant in plasma is controlled in accordance with the opening area ratio of the object to be etched. Specifically, the surface area of the shield is reduced as the opening area ratio of the object to be etched (i.e., the area to be etched) increases, so that the amount of scavenged etchant is reduced. On the other hand, the

surface area of the shield is increased as the opening area ratio of the object to be etched decreases, so that the amount of scavenged etchant is increased. Accordingly, it is possible to perform etching such that the amount of a critical dimensional shift is suppressed and a desired etched shape is obtained, irrespective of a pattern to be formed.

In the inventive etching method, the step of adjusting the surface area of the shield preferably includes the step of selecting one shield unit or a combination of two or more shield units from a plurality of shield units which have been prepared beforehand and have different size and forming the shield by the selected shield unit or the combination of shield units.

Then, the surface area of the shield unit is adjusted easily.

In this case, the plurality of shield units preferably includes at least two shield units whose main components differ from each other.

Then, the shield is constituted by a shield (or a plurality of shield units) containing a material exhibiting a high etchant scavenging ability as a main component and another shield unit (or a plurality of shield units) containing a material exhibiting a low etchant scavenging ability as a main component. With this configuration, a sharp change in the amount of an etchant on the shield (i.e., on the periphery of the wafer) is suppressed, so that the uniformity in the wafer surface regarding, for example, the etching ratio of the object to be etched, the selectivity between the object to be etched and its underlying material or the etched shape is improved.

In the inventive etching method, the gas preferably contains at least one gas selected from the group consisting of CF_4, CHF_3, C_4F_8, C_5F_8, C_4F_6 and C_2F_6.

Then, in the case of oxide-film etching (i.e., in a case where the object to be etched is an oxide film), if the surface area of the shield containing silicon as a main component is adjusted in accordance with the opening area ratio of the oxide film, the amount of

scavenged etchant for the oxide film (e.g., fluorine radicals in the plasma) is controlled. Accordingly, the amount ratio (e.g., C_xF_y/F ratio) between the deposition species (e.g., C_xF_y radicals in the plasma) and the etchant on the oxide film is optimized, thus ensuring a desired etched shape, while suppressing the amount of a critical dimensional shift during oxide-film etching, irrespective of a pattern to be formed.

As described above, according to the present invention, a shield is constituted by a combination of shield units selected from a plurality of shield units with different size, so that the surface area of the shield is adjusted in accordance with the opening area ratio of an object to be etched. That is, if the opening area ratio is high, the surface area of the shield is reduced so that the amount of scavenged etchant decreases. On the other hand, if the opening area ratio is low, the surface area of the shield is increased so that the amount of scavenged etchant increases. Accordingly, it is possible to perform etching such that the amount of a critical dimensional shift is suppressed and a desired etched shape is obtained, irrespective of a pattern to be formed.

The present invention relates to etching apparatus and etching methods. The present invention is effective especially when applied to oxide-film etching for forming a hard mask or a trench.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a view schematically showing a structure of an etching apparatus according to a first embodiment of the present invention.

FIG. **2** is a plan view showing a structure of a focus ring in the etching apparatus of the first embodiment.

FIG. **3** is a graph showing a result obtained by the present inventor regarding how a C_xF_y/F ratio varies when the radius of a Si focus ring is changed under the same etching

conditions as in an etching method according to the first embodiment.

FIG. **4A** is a view showing a case where an oxide film as an etching object is patterned into an inverted tapered shape. FIG. **4B** is a view showing a case where an oxide film as an etching object is patterned into a vertical shape. FIG. **4C** a view showing a case where an oxide film as an etching object is patterned into a tapered shape.

FIG. **5** is a graph showing a result obtained by the present inventor regarding a relationship between an opening area ratio of an oxide film and the radius of a Si focus ring allowing the etched shape of the oxide film to be a vertical shape under the same etching conditions as in the etching method of the first embodiment.

FIGS. **6A** through **6C** are cross-sectional views showing respective process steps of a method for forming a trench utilizing the apparatus and method for dry etching of the first embodiment.

FIGS. **7A** through **7C** are cross-sectional views showing respective process steps of a method for forming a trench according to a comparative example.

FIG. **8** is a cross-sectional view showing one of the process steps of the method for forming a trench according to the comparative example.

FIG. **9** is a view schematically showing a structure of a dry etching apparatus according to a second embodiment of the present invention.

FIG. **10** is a plan view showing a structure of a focus ring in the dry etching apparatus of the second embodiment.

FIG. **11A** is a graph showing a result obtained by the present inventor regarding a distribution of a C_xF_y/F ratio in a direction of the wafer radius in a case of using a Si focus ring under the same etching conditions as in a dry etching method according to the second embodiment. FIG. **11B** a graph showing a result obtained by the present inventor regarding a distribution of a C_xF_y/F ratio in a direction of the wafer radius in a case of

using a focus ring constituted by a SiC ring and a Si ring under the same etching conditions as in the dry etching method of the second embodiment.

FIG. **12** is a view schematically showing a structure of a conventional dry etching apparatus.

FIG. **13** is a plan view showing a structure of a focus ring in the conventional dry etching apparatus.

FIGS. **14A** and **14B** are views for explaining problems in oxide-film etching using the conventional dry etching apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

EMBODIMENT 1

Hereinafter, a etching apparatus and a etching method according to a first embodiment of the present invention will be described with reference to the drawings, taking oxide-film etching as an example.

FIG. **1** schematically shows a structure of the etching apparatus according to the first embodiment.

As shown in FIG. **1,** a substrate **150** to be processed is mounted on a lower electrode **102** provided on the bottom of a reaction chamber **101**. An upper electrode **103** is placed on the ceiling of the reaction chamber **101** to face the lower electrode **102** with a space in which plasma is to be generated interposed there between. An RF power supply **104** for applying power at, for example, 13.56 MHz to the lower electrode **102** is provided in the outside of the reaction chamber **101**. A gas inlet **105** for introducing a process gas into the reaction chamber **101** and a gas outlet **106** for letting out the process gas from the reaction chamber **101** is each provided through the wall of the reaction chamber **101**. A shield such as a focus ring **107** is provided on the lower electrode **102** to surround the

substrate **150**.

Although not shown, a silicon oxide film as an object to be etched is formed over the substrate **150** with a silicon nitride film, for example, interposed there between.

FIG. **2** is a plan view showing a structure of the shield comprised of the focus ring **107** shown in FIG. **1**, i.e., a focus ring according to this embodiment.

As shown in FIG. **2**, the shield such as the focus ring **107** of this embodiment is characterized by being constituted by a plurality of rings which have different radiuses and are arranged concentrically. Specifically, FIG. **2** shows that a first shield unit such as a first ring **107a** with a width of 2 cm and an outside radius of 12 cm, a second shield unit such as a second ring **107b** with a width of 2 cm and an outside radius of 14 cm and a third shield such as a third ring **107c** with a width of 2 cm and an outside radius of 16 cm are fit together with no gaps there between to form the shield such as the focus ring **107**. In this case, the inner side of the first ring **107a** serving as the inner side of the focus ring **107** is in contact with the edge of the wafer with a radius of 10 cm as the substrate **150**. In this embodiment, each of the rings **107a, 107b** and **107c** contains silicon as a main component.

In the case shown in FIG. **2**, the combination of the three rings **107a** through **107c** forms the focus ring **107** with a width of 6 cm and a radius (outside radius) of 16 cm. However, in this embodiment, the combination of the rings may be varied so as to arbitrarily change the width and radius of the focus ring **107**, i.e., the surface area of the focus ring **107**. For example, the first ring **107a** and the second ring **107b** may be combined to form a focus ring **107** with a width of 4 cm and a radius of 14 cm.

In this embodiment, the surface area of the focus ring **107** is the area of a portion of the focus ring **107** exposed to the plasma in the reaction chamber **101**, i.e., the total area of the upper and outside surfaces of the focus ring **107** surrounding the substrate (wafer) **150**.

Hereinafter, a method for dry etching an oxide film using the dry etching apparatus

of this embodiment shown in FIG. **1** will be described specifically.

First, a fluorocarbon gas (reactive gas) such as a C_4F_8, C_5F_8 or CF_4 gas, an Ar gas and an oxygen gas are supplied to the reaction chamber **101** through the gas inlet **105**, thereby generating a plasma made of these gases. An oxide film over the substrate **150** is then etched using the plasma. Specific etching conditions in this case are: the flow rate of, for example, C_4F_8 is 10 ml/min (under standard conditions); the O_2 flow rate is 5 ml/min (under standard conditions); the Ar flow rate is 400 ml/min (under standard conditions); the pressure in the chamber is 7 Pa; the RF power for plasma generation is 1500 W; and the substrate temperature is 20 °C.

In the above-mentioned plasma, the gasses introduced into the reaction chamber **101** are dissociated, thereby generating C_xF_y radicals (fluorocarbon radicals) to act as a deposition species and F radicals (fluorine radicals) to act as an etchant. These fluorine radicals react with silicon contained in the focus ring **107** and are scavenged, so that the fluorine radicals in the plasma decrease substantially. Since this decrease of the fluorine radicals is caused by the reaction between the focus ring **107** and the fluorine radicals, the fluorine radicals decreases in proportion to the surface area of the focus ring **107**. Accordingly, the amount ratio of the deposition species and the etchant (i.e., C_xF_y/F ratio) also increases in proportion to the surface area of the focus ring **107**.

On the other hand, in this embodiment, it is possible to change the surface area of the focus ring **107** by changing the radius (outside radius) of the focus ring **107** using various combinations of a plurality of rings, thereby changing the C_xF_y/F ratio in the plasma, as described above.

FIG. **3** shows how the C_xF_y/F ratio varies when the radius of a Si focus ring is changed under the same etching conditions as in this embodiment. In FIG. **3**, the abscissa represents the radius (outside radius) of the focus ring and the ordinate represents the

C_xF_y/F ratio. The C_xF_y/F ratio shown in FIG. **3** is obtained at the center of a wafer (substrate to be processed) with a radius of 10 cm in a case where the opening area ratio of an oxide film as an etching object is 80%. In a case where the substrate to be processed is a wafer with a radius of 10 cm, the radius of the focus ring is always greater than 10 cm.

As shown in FIG. **3**, as the radius of the Si focus ring increases, the amount of scavenged fluorine radicals increases, so that the C_xF_y/F ratio increases. In this case, a Si focus ring with a radius of 12 cm is formed only by the first ring **107a** of this embodiment, for example. A Si focus ring with a radius of 14 cm is formed by a combination of the first and second rings **107a** and **107b** of this embodiment, for example. A Si focus ring with a radius of 16 cm is formed by a combination of the first, second and third rings **107a, 107b** and **107c** of this embodiment, for example.

FIG. **3** also shows a relationship between the radius of the Si focus ring and the etched shape of the oxide film in a case where the oxide film is patterned into a line to have an opening area ratio of 80 %. As shown in FIG. **3**, as the radius of the focus ring increases, the etched shape of the line pattern formed out of the oxide film changes from an inverted tapered shape to a vertical shape and then to a tapered shape. This phenomenon occurs because fluorine radicals to act as an etchant for the oxide film decrease with the increase of the radius of the focus ring. That is, the etched shape of the oxide film changes depending on the radius of the Si focus ring. Under the same etching conditions as in this embodiment, a vertical shape, which is an excellent etched shape, is obtained in the range in which the radius of the Si focus ring is from 12 cm to 14 cm.

FIG. **4A** shows a case where the oxide film **151** over the substrate **150** is patterned into an inverted tapered shape under conditions in which dry etching is performed on the oxide film **151** using the resist pattern **152** as a mask. FIG. **4B** shows a case where the oxide film **151** is patterned into a vertical shape under the same condition. FIG. **4C** shows

a case where the oxide film **151** is patterned into a tapered shape under the same conditions.

FIG. **5** shows a relationship between an opening area ratio of an oxide film as an etching object and a radius of a Si focus ring allowing the etched shape of the oxide film to be a vertical shape. In FIG. **5**, the abscissa represents the opening area ratio and the ordinate represents the radius (outside radius) of the focus ring. The relationship shown in FIG. **5** was obtained under the same etching conditions as in this embodiment.

As shown in FIG. **5**, to achieve a vertical etched shape of the oxide film, the radius of the focus ring needs to be reduced as the opening area ratio increases. This is because of the following reasons. That is, as the opening area ratio increases, i.e., the area of the oxide film to be etched increases, a larger amount of etchant (fluorine radicals) is required during etching. Accordingly, to suppress the amount of scavenged fluorine radicals, the radius of the Si focus ring needs to be reduced. In contrast, as the opening area ratio decreases, i.e., the area of the oxide film to be etched decreases, a smaller amount of fluorine radicals is required during etching. Accordingly, to increase the amount of scavenged fluorine radicals, the radius of the focus ring needs to be increased.

As described above, in this embodiment, it is possible to set the radius (outside radius) of the focus ring **107** at an appropriate value by varying the combination of a plurality of rings. For example, if the focus ring **107** is constituted only by the first ring **107a** with the minimum radius, the surface area of the focus ring **107** is small so that the amount of scavenged (decreased) fluorine radicals is suppressed and the C_xF_y/F ratio decreases. Therefore, this structure is suitable for high opening area ratios. On the other hand, if the focus ring **107** is constituted by the combination of all the three rings **107a** through **107c**, the surface area of the focus ring **107** increases so that the amount of scavenged (decreased) fluorine radicals increases and the C_xF_y/F ratio increases.

Therefore, this structure is suitable for low opening area ratios.

As described above, in the first embodiment, the focus ring **107** is constituted by a combination of rings which are selected from a plurality of rings with different radiuses in such a manner that allows the focus ring **107** to have a surface area according to the opening area ratio of the etching object. Accordingly, the radius and the surface area of the focus ring **107** are adjusted easily in accordance with the opening area ratio of the etching object. Specifically, if the surface area of the focus ring **107** is adjusted by varying the combination of a plurality of rings each containing silicon as a main component in accordance with the opening area ratio of the oxide film as an etching object, it is possible to control the amount of scavenged fluorine radicals acting as an etchant for the oxide film. Accordingly, the amount ratio of a deposition species (fluorocarbon radicals) to the etchant (i.e., the C_xF_y/F ratio) on the oxide film is optimized, so that it is possible to achieve a desired etched shape while suppressing a critical dimensional shift during the oxide-film etching, irrespective of a pattern to be formed.

In addition, in the first embodiment, even in a case where the ~~pattern aperture~~ opening area ratio of the oxide film exceeds 80 %, if the radius of the focus ring **107** is reduced and the amount of scavenged fluoride radicals is suppressed so that the C_xF_y/F ratio is reduced, a vertical shape as a desired etched shape is achieved. For example, from the results shown in FIGS. **3** and **5**, in a case where the opening area ratio of the oxide film is 80 % and the same etching conditions as in this embodiment are adopted, if the third ring **107c** is removed from the focus ring **107** shown in FIG. **2**, an excellent etched shape is obtained. In other words, if a focus ring **107** with a radius of 14 cm constituted by a combination of the first and second rings **107a** and **107b** is used, an excellent etched shape is obtained.

In the first embodiment, the surface area of the focus ring **107** is adjusted by

varying the combination of the three rings **107a** through **107c** with radiuses of 12 cm, 14 cm and 16 cm, respectively. However, in the first embodiment, the number and radiuses of rings for use in adjustment of the surface area of the focus ring **107** are not specifically limited. It should be noted that the rings constituting the focus ring **107** are fit together with no gaps there between and the focus ring **107** has, at its center, an opening whose diameter corresponds to the diameter of the wafer (substrate **150**). Specifically, rings are combined such that the outer side of a ring with a smaller radius is in contact with the inner side of a ring with a larger radius, and the focus ring **107** is provided on the lower electrode **102** such that the inner side of the focus ring **107** is in contact with the edge of the substrate **150**. In the first embodiment, the focus ring **107** may be constituted by a single ring with the most appropriate radius according to the opening area ratio of the oxide film.

In the first embodiment, silicon is used as a main component of each of the rings constituting the focus ring **107** in order to control the amount of the scavenged etchant (fluorine radicals) in the plasma during oxide-film etching. However, even if the etching object is not an oxide film, materials appropriate for controlling the amount of the scavenged etchant for the etching object may be used as main components of the rings constituting the focus ring. In such a case, the same effects as in this embodiment are, of course, obtained.

In the first embodiment, C_4F_8 is used as a reactive gas (gas for plasma generation) for oxide-film etching. However, in this embodiment, the type of the gas for plasma generation is not limited and may be a gas containing at least one of CF_4, CHF_3, C_4F_8, C_5F_8, C_4F_6 and C_2F_6.

In the first embodiment, the focus ring **107** is mounted on the lower electrode **102** of the dry etching apparatus including the lower and upper electrodes **102** and **103** and surrounds the substrate **150**. The type of the dry etching apparatus to which the present

invention is applied is not limited. Specifically, the focus ring of the present invention may be mounted on an electrode in a reaction chamber of an etching apparatus of an ECR (electron cyclotron resonance) type or an ICP (inductively coupled plasma) type, for example, which does not include an upper electrode (but has an antenna and a coil). Even in such a case, the same effects as in this embodiment are obtained. In any type of the dry etching apparatus, the etching object such as a wafer may be, of course, mounted on an electrode with a support such as a pedestal interposed there between.

The dry etching apparatus and method of the first embodiment are not specifically limited in application, but are effective especially when applied to oxide-film etching for forming a hard mask or a trench for, for example, interconnection.

FIGS. **6A** through **6C** are cross-sectional views showing respective process steps of a method for forming a trench utilizing the apparatus and method for dry etching of the first embodiment.

First, as shown in FIG. **6A**, an underlying film **161** of, for example, a SiC film or a SiN film and an oxide film **162** of, for example, an SiO_2 film are formed in this order over a substrate **160** of, for example, silicon. Thereafter, a resist pattern **163** having an opening at a trench region is formed on the oxide film **162** with a publicly-known lithography technique. In this case, the oxide film **162** as an etching object has an opening area ratio of about 30 to 70 %.

Next, as shown in FIG. **6B**, the oxide film **162** is etched using the resist pattern **163** as a mask, thereby forming a trench **164**. In this case, the dry etching apparatus of this embodiment shown in FIG. **1** is used and the surface area of the focus ring **107** (see FIG. **2**) is adjusted in accordance with the opening area ratio of the oxide film **162**. Specifically, the radius (outside radius) of the focus ring **107** is changed by varying the combination of a plurality of rings. In this manner, the amount of the scavenged etchant in a plasma

generated in the reaction chamber **101** of the dry etching apparatus is controlled in accordance with the opening area ratio of the oxide film **162**, so that the oxide film **162** is patterned into a vertical shape. That is, the trench **164** with a desired shape and without a critical dimensional shift is formed.

Then, as shown in FIG. **6C**, the resist pattern **163** is removed, and then the trench **164** is filled with, for example, a barrier film and a copper film with a plating technique and a CMP (chemical mechanical polishing) process, for example, thereby forming an interconnect **165**. In this case, the trench **164** has a desired shape without a critical dimensional shift, so that the interconnect **165** has desired electric characteristics.

(Comparative Example)

Hereinafter, as a comparative example, trench formation using a conventional dry etching apparatus and a conventional dry etching method will be described with reference to the drawings.

FIGS. **7A** through **7C** are cross-sectional views showing respective process steps of a method for forming a trench according to the comparative example.

First, as shown in FIG. **7A**, an underlying film **171** of, for example, a SiC film or a SiN film and an oxide film **172** of, for example, an SiO_2 film are formed in this order over a substrate **170** of silicon. Thereafter, a resist pattern **173** having an opening at a trench region is formed on the oxide film **172** with a publicly-known lithography technique. In this case, the oxide film **172** as an etching object has an opening area ratio of about 30 to 70 %.

Next, as shown in FIG. **7B**, the oxide film **172** is etched using the resist pattern **173** as a mask, thereby forming a trench **174**. In this case, however, a conventional dry etching apparatus as shown in, for example, FIG. **12**, i.e., a dry etching apparatus with a focus ring

17 (see FIG. 13) for forming a contact hole with an oxide film as an etching object having an opening area ratio of about several percent, is used, so that the etched shape of the oxide film 172 is not a desired vertical shape but a tapered shape. Specifically, the width of the resultant trench 174 narrows toward the bottom.

Thereafter, as shown in FIG. 7C, the resist pattern 173 is removed, and then the trench 174 is filled with a barrier film and a copper film with a plating technique and a CMP process, for example, thereby forming an interconnect 175. However, the interconnect 175 does not have a desired shape depending on the shape of the trench 174, so that the interconnect 175 has poor electric characteristics, e.g., high resistance.

In the etching process shown in FIG. 7B, the flow rate of an O_2 gas in a process gas (e.g., a mixed gas of a reactive gas such as C_4F_8 or CHF_3, an Ar gas and an O_2 gas) to be introduced into a reaction chamber is increased, the reaction chamber is kept under a high degree of vacuum, or RF power for plasma generation (i.e., the ionization energy of an etchant) is increased, so that the oxide film 172 is patterned into a vertical shape. In this case, however, the selectivity between the oxide film 172 and the underlying film 171 (an etching stopper made of, for example, a SiC film or a SiN film) decreases, thus causing another problem that the etching reaches the underlying film 171 and the surface of the substrate 170 as shown in FIG. 8. On the other hand, in a case where the underlying film 171 is thick, another problem that the entire insulating film has a high effective dielectric constant arises because the relative dielectric constant of the underlying film 171 is about 5 to 7. This problem is noticeable especially in a case where a low-κ film having a relative dielectric constant of 3 or less is used instead of the oxide film 172.

EMBODIMENT 2

Hereinafter, a dry etching apparatus and a dry etching method according to a

second embodiment of the present invention will be described with reference to the drawings, taking an oxide-film etching as an example.

FIG. **9** schematically shows a structure of the dry etching apparatus of the second embodiment. In FIG. **9**, each member already described for the dry etching apparatus of the first embodiment is identified by the same reference numeral and the description thereof will be omitted herein.

The second embodiment is different from the first embodiment in the structure of the focus ring **108** disposed on a lower electrode **102** and surrounding a substrate **150** to be processed.

Although not shown, in this embodiment, a silicon oxide film as an etching object is also formed over the substrate **150** with, for example, a silicon nitride film interposed there between.

FIG. **10** is a plan view showing the structure of the focus ring **108** shown in FIG. **9**, i.e., a focus ring according to this embodiment.

As shown in FIG. **10**, the focus ring **108** of this embodiment is characterized by being constituted by a plurality of rings which have different radiuses and are arranged concentrically, as in the first embodiment. Specifically, FIG. **10** shows that a first ring **108a** with a width of 2 cm and an outside radius of 12 cm, a second ring **108b** with a width of 2 cm and an outside radius of 14 cm, a third ring **108c** with a width of 2 cm and an outside radius of 16 cm are fit together with no gaps there between to form the focus ring **108**. In this case, the inner side of the first ring **108a** serving as the inner side of the focus ring **108** is in contact with the edge of the wafer with a diameter of 10 cm as the substrate **150**.

The first and third rings **108a** and **108c** contain silicon as main components as in the first embodiment, whereas the second ring **108b** contains silicon carbide (SiC) as a

main component unlike the first embodiment.

In a case shown in FIG. **10**, the combination of the three rings **108a** through **108c** constitutes the focus ring **108** with a width of 6 cm and a radius (outside radius) of 16 cm. In this embodiment, the width and radius of the focus ring **108**, i.e., the surface area of the focus ring **108**, can be set at arbitrary values by varying the combination of rings. For example, if the first ring **108a** and the second ring **108b** are combined, a focus ring **108** having a width of 4 cm and a radius of 14 cm is formed.

In this embodiment, the surface area of the focus ring **108** is the area of a portion of the focus ring **108** exposed to a plasma in a reaction chamber **101**, i.e., the total area of the upper and outside surfaces of the focus ring **108** surrounding the substrate (wafer) **150**.

Hereinafter, a method for dry etching an oxide film using the dry etching apparatus of this embodiment shown in FIG. **9** will be described specifically.

First, a fluorocarbon gas (reactive gas) such as a C_4F_8, C_5F_8 or CF_4 gas, an Ar gas and an oxygen gas are supplied to the reaction chamber **101** through a gas inlet **105**, thereby generating a plasma made of these gases. Then, an oxide film formed on the substrate **150** is etched using the plasma. Specific etching conditions in this case are: the flow rate of, for example, C_4F_8 is 10 ml/min (under standard conditions); the O_2 flow rate is 5 ml/min (under standard conditions); the Ar flow rate is 400 ml/min (under standard conditions); the pressure in the chamber is 7 Pa; the RF power for plasma generation is 1500 W; and the substrate temperature is 20 °C.

In the above-mentioned plasma, the gasses introduced into the reaction chamber **101** are dissociated, thereby generating C_xF_y radicals (fluorocarbon radicals) to act as a deposition species and F radicals (fluorine radicals) to act as an etchant. These fluorine radicals react with silicon contained in the focus ring **108** and are scavenged, so that the fluorine radicals in the plasma decrease substantially. Since this decrease of the fluorine

radicals is caused by the reaction between the focus ring **108** and the fluorine radicals, the fluorine radicals decreases in proportion to the surface area of the focus ring **108**. Accordingly, the amount ratio of the deposition species and the etchant (i.e., C_xF_y/F ratio) also increases in proportion to the surface area of the focus ring **108**. The reactivity of each of the first and third rings **108a** and **108c** containing silicon as main components with respect to the fluorine radicals is higher than that of the second ring **108b** containing SiC as a main component.

On the other hand, in this embodiment, as described above, if the radius (outside radius) of the focus ring **108** is changed by varying the combination of the plurality of rings, the surface area of the focus ring **108** is adjusted, thereby changing the C_xF_y/F ratio in the plasma.

That is, in the second embodiment, the focus ring **108** is formed by combining rings which are selected from a plurality of rings with different radiuses in such a manner that allows the focus ring **108** to have a surface area according to the opening area ratio of the etching object. Accordingly, the radius and surface area of the focus ring **108** can be adjusted in accordance with the opening area ratio of the etching object. Specifically, if the surface area of the focus ring **108** is adjusted by varying the combination of a plurality of rings each containing silicon as a main component in accordance with the opening area ratio of the oxide film as an etching object, it is possible to control the amount of scavenged fluorine radicals as an etchant for the oxide film. Therefore, the amount ratio between the deposition species (fluorocarbon radicals) and the etchant (i.e., the C_xF_y/F ratio) on the oxide film is optimized, so that it is possible to obtain a desired etched shape while suppressing the amount of a critical dimensional shift during the oxide-film etching, irrespective of a pattern to be formed.

In addition, in the second embodiment, the focus ring **108** is constituted by a

combination of a plurality of rings containing different materials as main components. Specifically, the focus ring **108** includes at least a first ring **108a** containing, as a main component, silicon showing a high fluorine-radical scavenging ability and the second ring **108b** containing, as a main component, SiC showing a low fluorine-radical scavenging ability. Accordingly, a sharp change in the fluorine radicals density distribution on the focus ring **108** (i.e., on the periphery of the wafer as the substrate **150**) is suppressed, so that the uniformity in the wafer surface regarding, for example, the etching rate of the oxide film, the selectivity between the oxide film and its underlying material or the etched shape is improved. Hereinafter, effects of this embodiment will be described in detail:

FIG. **11A** shows, as a comparative example, a distribution of the C_xF_y/F ratio in a direction of the wafer radius in a case of using a Si focus ring with a width of 10 cm and a radius (outside radius) of 20 cm under etching conditions of this embodiment. FIG. **11B** shows a distribution of the C_xF_y/F ratio in a direction of the wafer radius in a case of using a focus ring (i.e., a modified example of the focus ring of this embodiment) constituted by a SiC ring with a width of 5 cm and a radius (outside radius) of 15 cm and a Si ring with a width of 5 cm and a radius (outside radius) of 20 cm under etching conditions of this embodiment. Each of the C_xF_y/F ratios shown in FIGS. **11A** and **11B** is measured at a point 3 cm above the surface of the wafer (i.e., semiconductor substrate).

As shown in FIG. **11A**, in the case of using the Si focus ring, the fluorine radicals are scavenged over the entire surface of the Si focus ring, so that the C_xF_y/F ratio increases sharply on the periphery of the wafer. Accordingly, the etching ratio of the oxide film, the selectivity between the oxide film and its underlying material or the etched shape, for example, changes sharply on the periphery of the wafer.

On the other hand, in the case of using the focus ring as the modified example of this embodiment constituted by the SiC ring and the Si ring, the reactivity between the SiC

ring and the fluorine radicals is smaller than that between the Si ring and the fluorine radicals. Accordingly, unlike the distribution shown in FIG. **11A**, no sharp change is observed on the periphery of the wafer in the distribution of the C_xF_y/F ratio in the direction of the wafer radius shown in FIG. **11B**. In other words, the C_xF_y/F ratio distribution in the wafer-radius direction shown in FIG. **11B** is substantially uniform even on the periphery of the wafer. That is, the C_xF_y/F ratio distribution in the wafer-radius direction is uniform as shown in FIG. **11B**, so that the uniformity in the wafer surface regarding, for example, the etching ratio of the oxide film, the selectivity between the oxide film and its underlying material or the etched shape is improved. The reason why C_xF_y/F ratio distribution in the wafer-radius direction shown in FIG. **11B** does not sharply decrease but is uniform even on the SiC ring is because of the influence of diffusion of the fluorine radicals.

In the second embodiment, the surface area of the focus ring **108** is adjusted by varying the combination of the three rings **108a** through **108c** with radiuses of 12 cm, 14 cm and 16 cm, respectively. However, the number and radiuses of rings for use in adjustment of the surface area of the focus ring **108** are not specifically limited as long as the focus ring **108** is constituted by at least two rings containing different materials as main components. It should be noted that the rings constituting the focus ring **108** are fit together with no gaps there between and the focus ring **108** has an opening whose diameter corresponds to the diameter of the wafer (substrate **150**) at its center. Specifically, rings are combined such that the outer side of a ring with a smaller radius is in contact with the inner side of a ring with a larger radius, and the focus ring **108** is provided on the lower electrode **102** such that the inner side of the focus ring **108** is in contact with the edge of the substrate **150**.

In the second embodiment, SiC is used as a main component of the second ring

108b i.e., as a material showing a low fluorine-radical scavenging ability. Alternatively, quartz (SiO_2), alumina (aluminum oxide: Al_2O_3) or yttrium oxide (Y_2O_3) may be used, for example. In such a case, the same effects are obtained.

In the second embodiment, the focus ring **108** includes at least the first ring **108a** containing, as a main component, silicon showing a high fluorine-radical scavenging ability and the second ring **108b** containing, as a main component, SiC showing a low fluorine-radical scavenging ability. However, even in a case where the etching object is not an oxide film, if a focus ring including at least a ring containing, as a main component, a material showing a high scavenging ability to an etchant for the etching object and a ring containing, as a main component, a material showing a low scavenging ability to the etchant is used, the same effects as in this embodiment are, of course, obtained.

In the second embodiment, at least one of the plurality of rings constituting the focus ring **108** preferably contains, as a main component, the same material as the etching object. Then, in the case of etching, for example, an oxide film (SiO_2 film), if a focus ring including a ring of SiO_2 is used, the effective area to be etched (the SiO_2 area) is the sum of the area of a portion of the oxide film to be etched (a portion under the opening of the resist mask) and the surface area of the SiO_2 ring. In other words, if the focus ring is formed using a ring containing, as a main component, the same material as the etching object, the effective etched area of the etching object having a low opening area ratio is increased. Accordingly, the amount of the etchant to be supplied to a portion of the etching object to be etched is made uniform, irrespective of the degree of the opening area ratio of the etching object. As a result, a plurality of etching objects with various opening area ratios are etched into desired etched shapes using the same dry etching apparatus.

In the second embodiment, C_4F_8 is used as a reactive gas (gas for plasma generation) for etching the oxide film. However, in the second embodiment, the type of

the gas for plasma generation is not limited and may be a gas containing at least one of CF_4, CHF_3, C_4F_8, C_5F_8, C_4F_6 and C_2F_6.

In the second embodiment, the focus ring **108** is mounted on the lower electrode **102** of the dry etching apparatus including the lower and upper electrodes **102** and **103** to surround the substrate **150**. However, the type of the dry etching apparatus to which the present invention is applied is not limited. Specifically, the focus ring of the present invention may be mounted on an electrode within a reaction chamber of an etching apparatus of an ECR type or an ICP type which does not have an upper electrode (but has an antenna and a coil). Even in such a case, the same effects as in this embodiment are obtained. In any type of the dry etching apparatus, the etching object such as a wafer may be, of course, mounted on an electrode with a support such as a pedestal interposed there between.

The dry etching apparatus and method of the second embodiment are not limited in application, but are effective especially when applied to oxide-film etching for forming a hard mask or a trench for, for example, interconnection.